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# DESIGN CHARACTERISTICS OF A CONICAL SHOCK TUBE FOR THE SIMULATION OF VERY LARGE CHARGE BLASTS (U)

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# DESIGN CHARACTERISTICS OF A CONICAL SHOCK TUBE FOR THE SIMULATION OF VERY LARGE CHARGE BLASTS

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ABSTRACT: Experiments with a cone-shaped shock tube using high explosives as the driving means are described. Only a small quantity of explosive within the cone is required to produce a sector of a spherical shock wave with characteristics equivalent to those of a similar shock from a much larger quantity of explosive fired in the open. The charge amplification factor is computed as the ratio of the solid angle of a sphere to the solid angle intercepted by the cone. Since the amplification factor may be made quite large, the experimental problem of studying large high explosive blasts in a variety of fluid media can be drastically simplified with the use of the device.

A 2° cone performing with 30 percent efficiency has provided an amplification of 3000. A blast wave equivalent to that from 45 pounds of explosive has been produced in this cone using only 7.5 grams of charge.

Based on these and other experimental results, the possibilities of generating blast waves equivalent in magnitude to those from atomic weapons are discussed. In particular, possible configurations of cones capable of producing blast waves equivalent to those from 0.5 and 20.0 kilotons of TNT are presented.

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## ILLUSTRATIONS

# DESIGN CHARACTERISTICS OF A CONICAL SHOCK TUBE FOR THE SIMULATION OF VERY LARGE CHARGE BLASTS

## INTRODUCTION

This report concerns the generation of explosion blast waves in air by a method that uses only a small fraction of the amount of explosive normally required for generating equivalent blasts in the field.

Consider a sphere of explosive, Figure 1a. After initiation at the center, any sector of this sphere expands in a way that is identical to any other equivalent sector. Suppose that a sector of this sphere of explosive were removed and placed at the apex of a conical steel enclosure having the same angle as the sector, Figure 1b; also suppose that the walls of this conical steel enclosure extended beyond the charge and were strong enough to withstand the blast. When the cone of explosive was initiated it would expand within the confines of the cone in the same manner as it would if it were part of the full sphere.

The net effect would be that blast characteristics of a full sphere of explosive detonated in the open would be produced identically in the cone, employing only a fraction of the amount of explosive. In fact, the fraction would be the ratio of the weight of the charge used in the cone to the weight of the full sphere; or, what amounts to the same thing, the ratio of the solid angle of the cone to that of a sphere. In the remainder of this report it will be convenient to refer to the "amplification factor", defined as the reciprocal of this ratio.

## SMALL CONE EXPERIMENTS

To check the basic idea described above, an initial experiment was performed in the summer of 1958. The successful results of that test, and details of instrumentation and analysis, are reported in references (a) and (b). A photograph of the 22° cone that was used is shown in Figure 2; Figure 3 is a diagram of the experimental arrangement. The angle of this cone was chosen somewhat arbitrarily; theoretically, it provided an amplification factor of 110. (Notice that the explosive used was not a bare conical charge, but a cylindrical plastic cased detonator, available commercially.)

The characteristic features of a blast pressure-time record are shown in Figure 4. This may be used for reference purposes when examining actual records obtained in the conical shock tube. The maximum pressure in the pressure-time trace is the peak overpressure. This pressure occurs at the shock front and is developed instantaneously, for almost all practical purposes. Behind the front the pressure gradually decays to ambient pressure. (The oscillations at early times are attributed to instrumental inadequacies.) The time integral of the positive pressure is the positive impulse, and is represented by the crosshatched area under the pressure-time curve. The time required for the positive pressure to decay to ambient is called the positive duration.

Figure 5 shows some of the records obtained with the cone. The quality of the cone records, compared with free-air blast records obtained in the field is, clearly, quite good. Measurement of the peak pressure and impulse showed that an actual amplification of about 60 was achieved.

The conclusion drawn from this initial test was that the cone idea basically works; but since steel deforms, conducts heat, and introduces frictional losses to the expanding gas, the efficiency of the device was less than 100 percent. The efficiency of this first test cone was measured to be about 60 percent. It was learned also that an exact cone shape for the explosive charge itself is not important for satisfactory performance of the conical tube. The inherent tendency of the gas to expand symmetrically, regardless of its earlier history, results in a stable, spherically-expanding shock front within the cone.

A second cone was built with an angle of 2° to determine the effect of cone angle on efficiency. The 2° cone has a theoretical amplification factor of 10,000. Figure 6 shows three views of this cone. Figure 7 is a diagram of the experimental arrangement. Again, as with the first cone, tests with this 2° cone produced good results, as compared with those obtained in the field. Figure 8 shows the excellence of the records. An actual amplification of 3,000 was realized, demonstrating that truly spectacular amplifications are possible, provided one is willing to accept a moderate reduction in efficiency. In this case, an efficiency of about 30 percent was obtained.

A comparison of the performance of the 2° and 22° cones indicates that large amplifications may be achieved without corresponding losses in efficiency as the cone angle is decreased. In this case, an increase of two orders of magnitude in amplification is realized, whereas the efficiency is only halved. It must be noted, however, that a charge-size effect may exist that has yet to be examined. (With larger charges, heat losses should be reduced because of improved surface-to-volume ratios.) Also, the cones used to date have been fabricated using relatively rough rolling techniques; thus, they have not been held to very exact tolerances. It is conceivable that greater care in fabrication could lead to smaller boundary layer losses.

## LARGE CONE DESIGN FEATURES

It is felt that the major questions about the performance of conical shock tubes have been evaluated under conservative conditions, and although data from large scale cone-charge configurations are not yet available, speculation is in order with regard to the use of this technique for generating very large charge blasts.

First, several general features require some consideration. With conical shock tubes, the distance at which blast characteristics are obtained from a given quantity of simulated charge is not reduced. Only the amount of charge required to do the job is reduced. Consequently, the length of the conical tube must equal the distance at which a desired blast wave shape is normally found in the field, if the same effect is to be achieved. Scaling laws, however, hold within the cone. Each cone will have a particular, practical amplification factor, which, when multiplied by the weight of charge actually fired in the cone, will give the simulated charge weight. An important aspect of cone design that helps fix the shape of a cone is the working space needed in the cone to evaluate properly the effects being studied. The size of the opening of the cone, together with the length, fix the angle of the cone, and thus its amplification factor. The amplification factor, after adjustment for cone losses, determines the amount of explosive that must be fired in the cone to produce the desired blast. The subsequent discussion will be concerned with two particular configurations.

Consider a requirement for a blast wave with a peak overpressure of 100 psi and a positive duration of 50 milliseconds. Such a wave is found at about 300 feet from a 1,000,000-pound, or one-half-kiloton, TNT charge. To produce such a blast wave, a conical shock tube on the order of 300 feet in length is required -- not an unreasonable length when compared to existing plane-wave shock tube facilities. Theoretically, the amplification factor for a tube of such a length, having an opening of 4 feet at the far end, is about 100,000. With this amplification factor, a ten-pound charge is required to produce the desired blast if 100 percent efficiency is assumed. The air shock pressure as a function of distance from explosives is well established, and calculations show that the strength requirement for the main body of the cone could be met adequately, using one-half inch thick steel for the major portion of its length. A firing block to contain the explosive during detonation is an unusual problem, but not an unreasonable one. Small and large scale tests with up to 62 pounds of explosive, fired in an 18-inch ID gun section, have been performed at NOL and have shown that minimal deformation results when an air space greater than one charge diameter is used between the explosive and the enclosure walls.

A recent test, in which a 10-pound explosive charge was fired in a 5-inch gun, indicated that gun barrels are well suited for firing-block applications. In this test, the explosive was in the form of a cylinder 1.5 inches in diameter and 8 feet long. The charge axis was aligned with the axis of the gun barrel, the charge resting in a styrofoam support.

The effect on the blast wave of having a large air space about the charge in the firing block has been explored recently, and has been found to be insignificant, at least from the 100 psi peak-pressure level down.

Cone end effects are of varying importance, depending on the application. Rarefaction waves that travel back from the open end of the tube can be eliminated by means of diffusers that have been reported in the literature. If the blast noise from the end of a tube is considered a problem, closure of the end is feasible, and the blast energy will be contained and eventually dissipated to the walls as heat. Only minimal transmitted noise from the walls will be heard.

BLAST SIMULATION FROM KILOTONS OF TNT

At 2000 feet from a 20-kiloton HE charge, the peak overpressure is about 20 psi, and the positive duration about 1/3 second. Therefore, if it were desired to reproduce such a blast wave with a conical shock tube, having a 20-foot diameter working section, the cone required would be 2000 feet long and would have an angle of about 1/2 degree. About 250 pounds of explosive would be required, if 100 percent efficiency were assumed. A more practical assumption for the efficiency might be 25 percent, in which case, 1000 pounds of explosive would be needed. Here, the use of a 21-inch gun barrel as a firing block might be feasible. It should be remembered that such guns normally use propellants in similar quantities, and that the energy produced by explosives, pound for pound, is of the same order as that produced by propellants. The chief difference is that for explosives, the energy release is faster, and involves a pressure wave within the charge of several million psi. However, it is well established by theory and experiment, as well as by the empirical tests mentioned above, that these pressures are attenuated very rapidly in the surrounding air, and are down to levels that may be accommodated by metals (within their elastic range) within a very short distance. For example, when more than one charge diameter of air space is kept between the charge surface and metal enclosure, practical metal thicknesses are determined in design considerations.

Table I summarizes the features of the two possible large-blast cone designs discussed.

SUMMARY AND CONCLUSIONS

Shock tubes provide a convenient means for the study of blast reflection, diffraction, and drag effects on objects present in the flow. Laboratory-scale cones, employing high explosives as the driving means, have been used successfully to generate spherically expanding blast waves identical in all practical respects to those produced by explosions in the field. The results obtained indicate promising possibilities for the use of a large-scale, explosive-driven conical shock tube to simulate the blast from kiloton quantities of explosive.

Other interesting possible applications include:

1. Convenient blast studies at simulated altitudes by evacuating a cone.

2. Studies of shock waves in other media, such as in gases other than air, and in water.

Table I

Summary of Design Features of 1/2- and 20-Kiloton Blast Cones

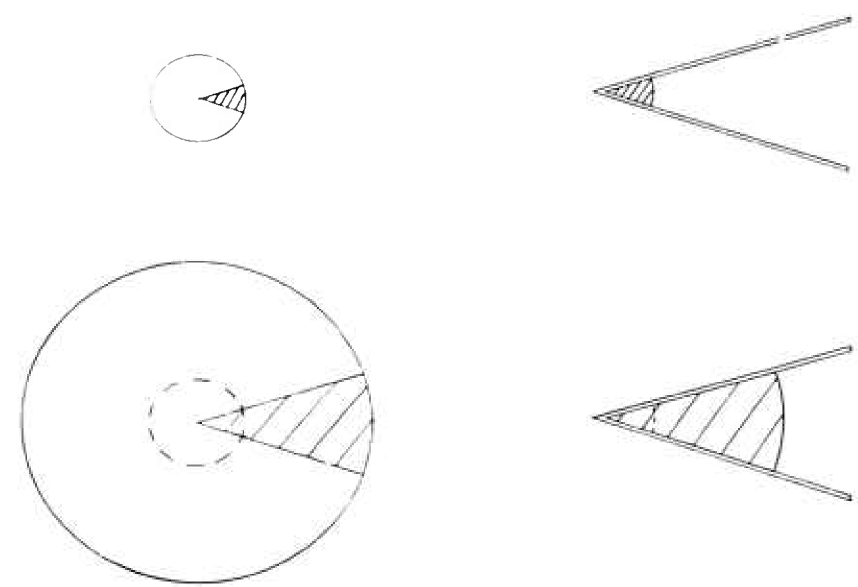
| Blast Characteristics | | | Cone Characteristics | | |
|---|---|---|---|---|---|
| Charge Weight (simulated) | Peak Over-pressure | Positive Duration | Length | Work Space Diameter | Charge Weight (to be fired) |
| kilotons | $lbs/in^2$ | msec | feet | feet | pounds |
| 1/2 | 100 | 50 | 300 | 4 | 10 (40)* |
| 20 | 20 | 360 | 2000 | 20 | 250 (1000)* |

* Figures in parenthesis refer to weight of charge required assuming an efficiency of 25 percent.

## REFERENCES

(a) W. S. Filler, "An Explosive Driven Conical Shock Tube for the Study of Spherical Shock Waves," Proceedings of the 3rd Shock Tube Symposium, March 1959; Air Force Special Weapons Center Report No. SWR-TM-59-2.

(b) W. S. Filler, "Measurements on the Blast Wave in a Conical Tube," The Physics of Fluids, 3, 444 (1960).



(A.) SECTOR OF EXPLOSIVE WITHIN EXPLOSIVE SPHERE

(B.) SECTOR OF EXPLOSIVE CONFINED BY CONE

FIG. 1 SECTOR PRINCIPLE

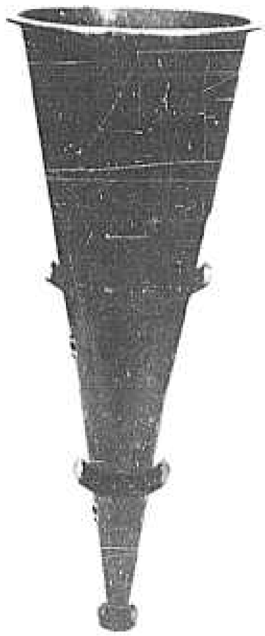


FIG. 2 22° CONE

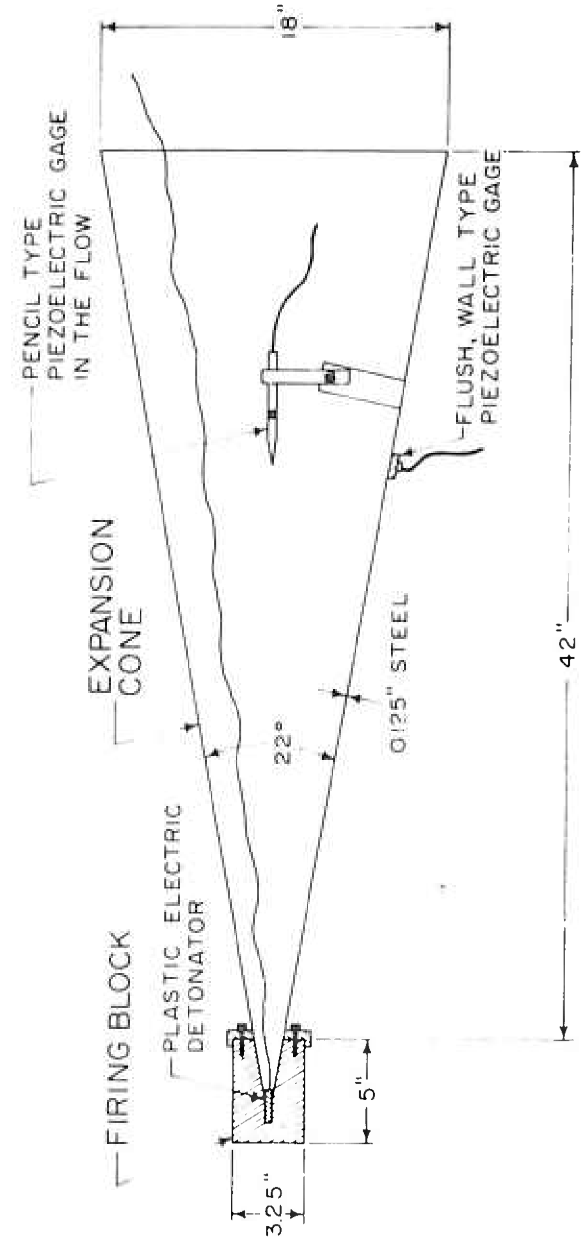



FIG. 3 DIAGRAM OF 22° CONE EXPERIMENT

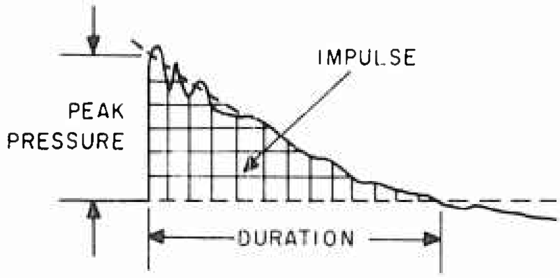
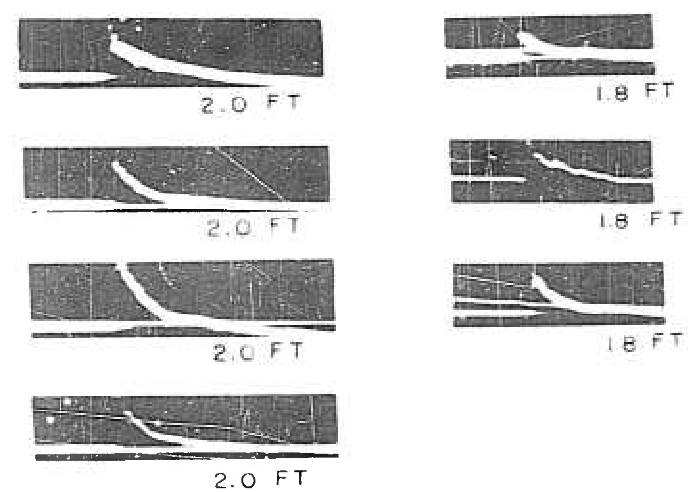



FIG. 4 SPHERICAL SHOCK WAVE PARAMETERS

CONE SHOT: 1/2 GRAM DETONATOR CHARGE

APPROXIMATE PEAK PRESSURE 35 $LB/IN^2$

APPROXIMATE POSITIVE DURATION 0.5 MILLISECONDS




FREE-AIR SHOT: 55 GRAM SPHERICAL CHARGE

APPROXIMATE PEAK PRESSURE 50 $LB/IN^2$.

APPROXIMATE POSITIVE DURATION 0.5 MILLISECONDS

FIG. 5 COMPARISON OF TYPICAL RECORDS FROM A 22° CONE AND A FREE-AIR SHOT. ALL FOUR CONE RECORDS AND ALL THREE FREE-AIR RECORDS WERE OBTAINED ON SINGLE SHOTS. (RELATIVE AMPLITUDE OF TRACES IS NOT SIGNIFICANT.)

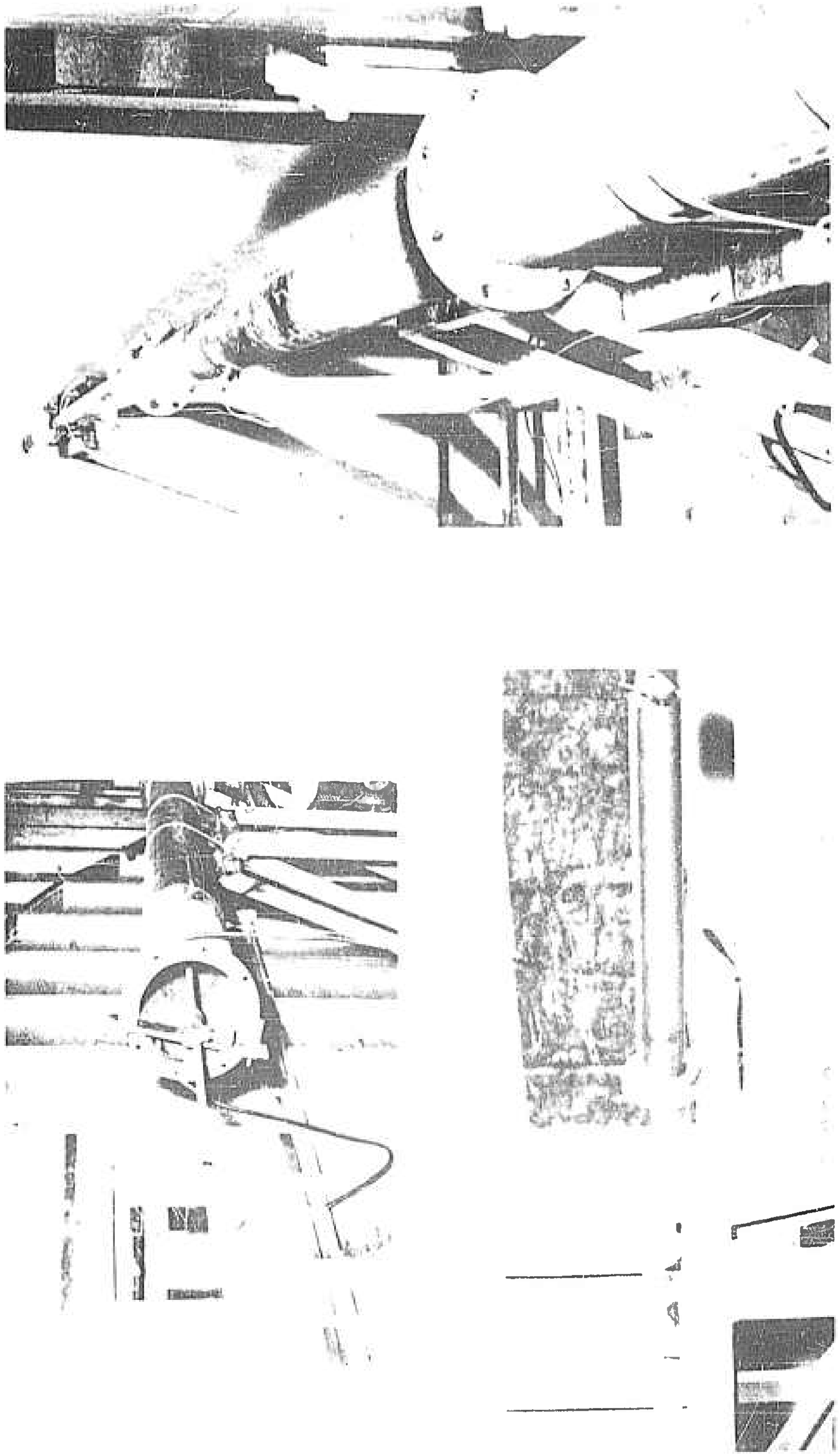


FIG. 6 VIEWS OF 2° CONE

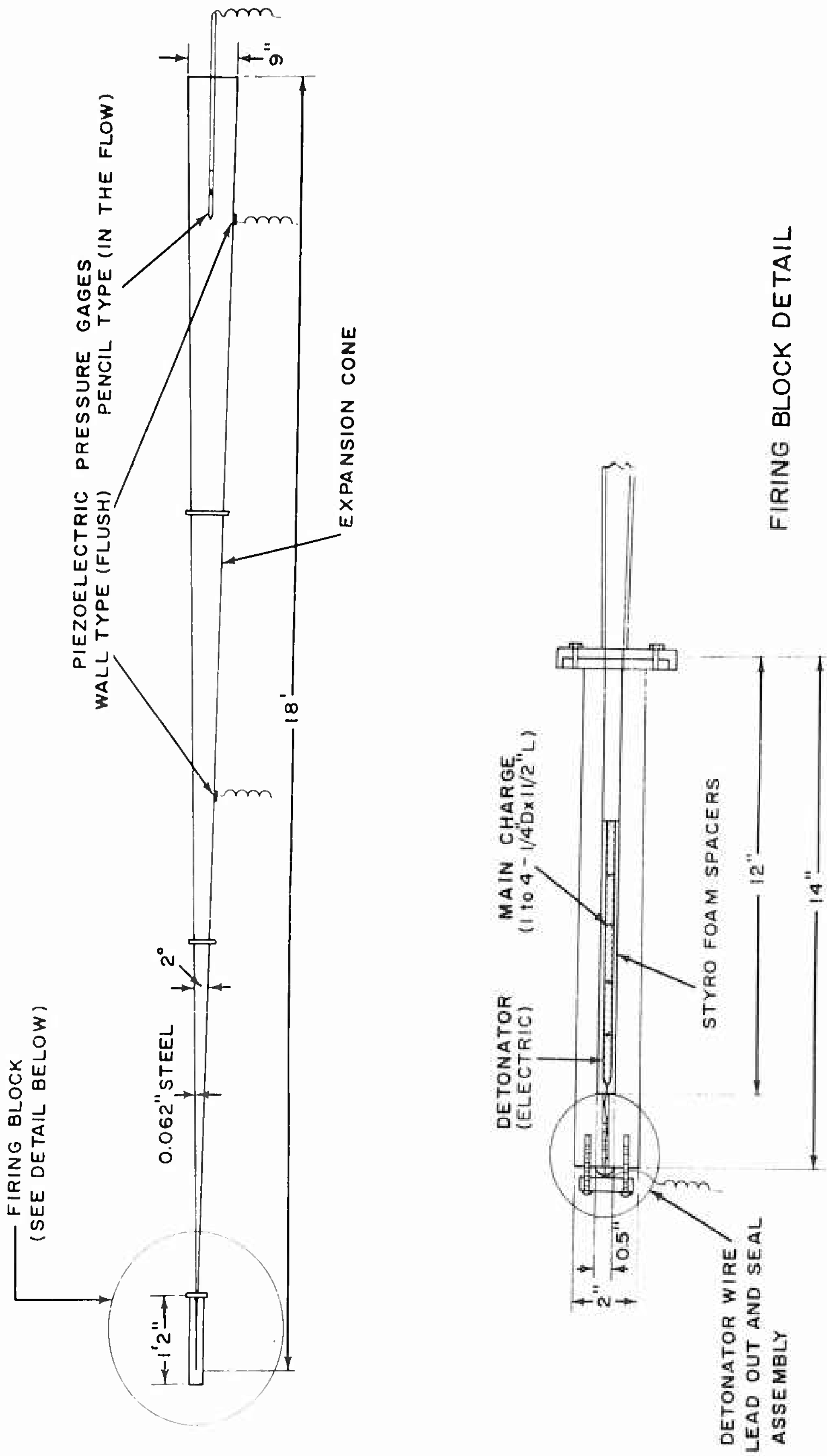



FIG. 7 DIAGRAM OF 2° CONE EXPERIMENT

| CHARGE WEIGHT FIRED GM | CHARGE WEIGHT SIMULATED LB | GAGE DISTANCE FROM CHARGE FT | PEAK PRESSURE LB/IN$^2$ | POSITIVE DURATION MSEC |
|---|---|---|---|---|
| 2.5 | 15 | 16 | 20 | 3.5 |
| | | 8 | 100 | 1.5 |
| 7.5 | 45 | 16 | 40 | 3.5 |
| | | 8 | 200 | 1.5 |

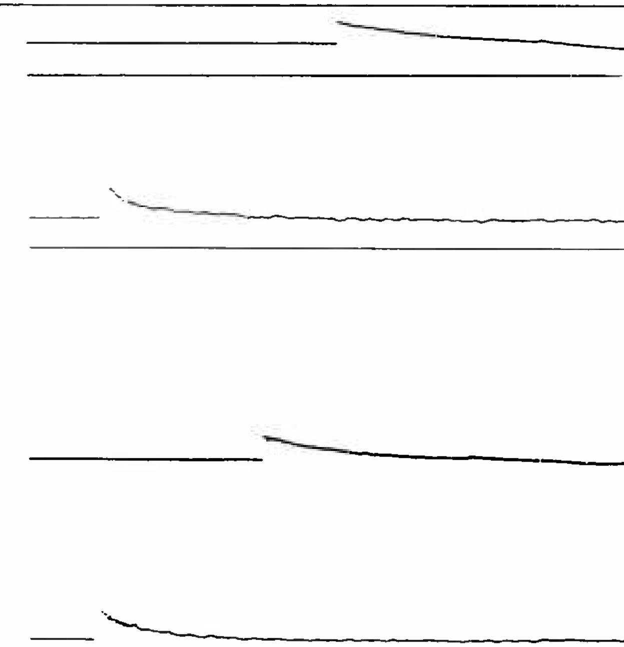


FIG. 8 TYPICAL RECORDS FROM 2° CONE
(RELATIVE AMPLITUDE OF TRACES IS NOT SIGNIFICANT)